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FINAL REPORT

VELOCITY TOLERANCE OF ESCAPE SYSTEMS

6585TH TEST GROUP
HOLLOMAN AIR FORCE BASE, NEW MEXICO

1 DECEMBER 1980

ARMAMENT DIVISION
AIR FORCE SYSTEMS COMMAND • UNITED STATES AIR FORCE
EGLIN AIR FORCE BASE, FLORIDA

This technical report has been reviewed and is approved for publication.

Robert E. Beale

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escape systems	velocity window	ejection
KEAS	transonic	statistical analysis
drag run	dynamic pressure	drag coefficient
sustainer rockets		

20. ABSTRACT (Continue on reverse side if necessary ...)

... Air Force escape system tests were analyzed for ... target velocity should not be stated in terms of ... serious under testing of maximum velocities ... tolerance is essentially independent of the ... of plus/minus (±) 23.5*KEAS will ...

*KEAS - Knots Equivalent Air Speed

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INTRODUCTION The firing of a rocket sled to a given velocity at a given point on the Test Track is a difficult task. It involves the prediction of a number of relatively unknown variables. For example, for economic reasons, the propulsion often consists of over-age rocket motors whose thrust characteristics may be out of the manufacturer's specifications. Also, the motors' thrust will be affected by the temperature they have been subjected to during the several hours prior to their firing. Further, the air density and thus the sled drag are affected by the temperature at the time of the firing.

In escape systems tests (reference 1) which are usually ejection seats, there is an additional complication. MIL-S-9479B (reference 2) specifies the ejection velocity in terms of Knots Equivalent Air Speed (KEAS), that is, the air speed one would have at sea level and 59 degrees Fahrenheit. This is necessary for comparison of equivalent dynamic pressures. We can do this, of course, but it does involve the prediction of both the temperature and the barometric pressure at the time of the sled firing.

These variables and others of lesser significance have led the Track to use 'plus or minus 10 per cent' as the tolerance to which it can produce a given ejection velocity at a given point on the Track. It is probably not coincidental that MIL-STD-846C (reference 3) states that a velocity outside of $\pm 10\%$ of the target velocity shall be used for declaring a mission a "no test". The target velocity is the velocity specified by the Track customer for the point of ejection. In any event, this tolerance has withstood the test of time. The Track can and has produced escape system test velocities time after time and year after year within this tolerance.

It should be noted that in order to assure a velocity close to the target velocity, a drag run must be conducted at the maximum velocity. No ejection is made during the drag run which is usually conducted at the maximum velocity of the test series. From this run, the 'coefficient of drag' is computed for the entire velocity range.

In order to be certain that a given test is conducted within ±10% of its target velocity a 'velocity window' is set. Thus, if a test sled should arrive at the ejection point at a velocity above +10% or below -10%, on-board initiators are not armed and no ejection would occur. This is a rare event, and to the author's knowledge it has not occurred during the past three years.

For many velocities, ±10% appears to be a reasonable tolerance range. That is, 200 KEAS ±10% gives a possible test range from 180 to 220 KEAS. However, as the velocity goes up, the tolerance becomes progressively more conservative.

For example, a 600 KEAS test (as required on most test programs by references 2 and 3) would give a velocity tolerance ranging from 540 KEAS to 660 KEAS. Not only will the low end of the velocity range be completely out of the critical transonic region but there will be a tremendous difference in dynamic pressure. Dynamic pressure is that force per unit area that the escape system is subjected to when it is ejected into the air stream. Dynamic pressure is a critical factor in both the functioning of the components of the escape system and in the potential for injury to the crew member.

Dynamic pressure is a function of velocity squared. A velocity range of 540 KEAS to 660 KEAS gives a dynamic pressure range of 987.5 psf to 1,475 psf. That is, for 600 KEAS ±10% the dynamic pressure is 1,219.3 psf, plus 20.9%, minus 19.1%. It is this large range of dynamic pressure which causes a two-sided

dilemma which led to this study.

<u>DILEMMA</u> In order to meet the requirements of MIL-S-9479B (reference 2) and MIL-STD-846C (reference 3) the customer and his contractor must request a test at the maximum aircraft air speed or 600 KEAS, whichever is less. However, no customer wants to risk subjecting his escape system to a possible 10% overtest in velocity which would give a 20.9% overtest in dynamic pressure. His system might fail in a 20% overtest while it otherwise might pass a nominal test with ease.

This usually leads the customer/contractor to negotiate a new maximum velocity with the Test Track. A new velocity whose high side will not exceed, or will not exceed more than a few per cent, the old maximum velocity. For example, on a recent 450 KEAS test (maximum aircraft air speed) we actually targeted for 409 KEAS ±10% for a range of 368 KEAS to 450 KEAS. Note that on this test, the range of 368 KEAS to 405 KEAS would not even meet the minimum specification.

On the other side of this dilemma are the air crew members who will be ejected from an aircraft using this escape system.

It is reasonable to expect that a 450 KEAS system has been tested at a velocity greater than 405 KEAS and certainly to a velocity greater than 368 KEAS. In fact, from the viewpoint of the ejectee, it would be desirable if the system had been tested to something greater than 450 KEAS.

In summary, the dilemma appears to be: How can we conduct a test that we can be sure will not grossly overtest the escape system and at the same time be sure that it will be high enough to adequately test the system for the ejectee user? In general, a tolerance of ±10% will not do both.

ANALYSIS   The initial thrust of the analysis was to try the obvious. That is, based on past testing history, could we reduce the tolerance to something less than $\pm 10'$ and if so, to what?

All of the Air Force escape system tests conducted at the Test Track during the past three years (1977, 1978, 1979) were selected for analysis with two exceptions.

EXCEPTION 1: None of the 17 static tests were included in the analysis. There is no question of our ability to conduct a zero (0) velocity test and the inclusion of these tests would unnecessarily distort the analysis.

EXCEPTION 2: On three of the dual seat ejections, the sled velocity at the time of the ejection of the second seat, was not recorded. The ejection velocity would have been very close to that of the first seat and apparently was not requested by the test customer. However, in the interest of accuracy, no attempt was made to estimate the velocity of these three ejections and they were omitted.

The exclusion of these twenty (20) data points reduces the number available for analysis from 104 to 84. However, this still leaves almost three times the number of points required for a statistically "large" sample size (reference 4).

The escape systems tested used sleds with the external configuration of the A-10, A-37, F-16, F-111, and B-1 aircraft. This gave a complete range of sled weights and drag coefficients. In addition, they encompassed single, dual and four seat ejection sequences.

Considerable thought was given as to whether to analyze the velocity of only the first seat of a two/four seat ejection or if all seats should be analyzed individually as to how close they came to the target velocity. Here at the Test Track we have always attempted to eject all seats within $\pm 10''$ of the target velocity. This is evidenced by the fact that we often fire sustainer rockets after

one or more seats have ejected in order to keep the sled near the target velocity. Further, MIL-STD-846C (reference 3) appears to require this as it states ". . . until the time that escape system/sled separation occurred." If the escape system is in several parts (several seats), the velocity must be maintained until the last part (last seat) has separated.[1]

A brief statistical analysis was made of the per cent that each of the 84 data points deviated from its target velocity. The data and the percentage of deviation are shown in Tables 1 and 2. The mean of the percentage of deviation was 0.38 per cent which is not remarkable (ideally the mean would be zero [0]). However, the standard deviation was 3.09 per cent and this has great significance. Basically, this means that approximately 68% of our tests will fall within ±3.09 per cent, that only one test in 20 will fall outside of ±6.18 per cent and only 3 tests out of 1,000 will fall outside of ±9.27 per cent. Or simply put, ±10% is an extremely conservative tolerance. A plot of the data is even more enlightening. See Figure 1.

The actual velocity of each data point has been plotted against its target velocity. If each test had been conducted at its target velocity, these points would all lie in a straight line. Obviously, they were not and this graph shows the resultant scatter of data.

[1] For comparison, an analysis was made of only the first seats. It showed an increase in the standard deviation of only 0.35 per cent, i.e. no significant difference.

For comparison, +10% velocity tolerance lines have been added to the graph. The lines enclose a "V" shaped area beginning at zero KEAS. Notice particularly that some of the lower velocity tests are just inside the tolerance. Conversely, at the high velocity end there are large areas of space between the data points and the tolerance limits. This is most evident by consulting Figures 2 and 3 which are the same data with expanded scales.

Note that at a target velocity of 450 KEAS one test achieved a velocity of only 417.4 KEAS or 32.6 KEAS low. Yet it was not even close to its tolerance limit of 405 KEAS. This occurred because of unexpected low motor thrust. In this instance, it seems that it would have been better to have not conducted this test. That is, to have gone through the velocity window without ejecting the seat and then re-tested later.

From studying these three figures, it is clear that we have difficulty in conducting low velocity tests that should be conducted and at high velocities, we may easily conduct tests that probably should not be conducted.

In any event, it is obvious that a ±10% tolerance does not describe the data recorded during the past three years. In fact, it appears that the scatter of actual velocity data points is essentially independent of the target velocity. For a verification of the independence, see Appendix A. Note that the range of 17.7 KEAS for 8 data points at 150 KEAS is identical to the range of 17.7 KEAS for the 8 data points at 576 KEAS.

Since the scatter is independent of the target velocity, it might be more accurately described in terms of KEAS rather than per cent. With this in mind, a brief statistical analysis was made of the number of KEAS that each of the 94 data points was from its target velocity. See Table 3.

The mean was 0.99 KEAS which is not remarkable. Its standard deviation was 7.84 KEAS and contains some important implications. That is, approximately 68% of our tests will fall within ±8 KEAS and that only one test in twenty (20) will fall outside of ±16 KEAS. These data were re-plotted and are shown in Figure 4 with ±16 KEAS tolerance lines.

Only two points are not enclosed by the ±16 KEAS tolerance lines. Note, that for two standard deviations and 84 data points, one should expect four data points to be outside of the tolerance lines. However, the one point is so far out of tolerance (more than 4 standard deviations) that it opened up the tolerance so large that two other points (at 250 and 325 KEAS) were included in the ±16 KEAS.

The scatter of data fits the ±16 KEAS tolerance lines at all target velocities. Our assumption, that the scatter of data is independent of the target velocity, appears quite valid.

It is the opinion of the author that ±16 KEAS might be a bit too restrictive. Certainly, a customer could object to taking a 1 out of 20 chance that no ejection would occur. And for a few KEAS more, the probability of ejection could be greatly increased.

For example, a tolerance of ±23.5 KEAS would be 3.0 standard deviations and that is a tolerance which we can hit 997 out of 1000 times. This would also appear to be a good compromise solution to the problem posed in the Dilemma Section of this report. That is, 623.5 KEAS on a 600 KEAS test is an overtest in velocity of only 3.9% and an overtest in dynamic pressure of only 8.0%. This is

a worst case condition and should be an a[illegible] for the customer. Similarly, 576.5 KEAS, which [illegible] gives an undertest of only 7.7 in dyna[illegible] that this is also a worst case, this should be [illegible] of adequately testing the escape system for the [illegible]

While the Test Track generally recommends a toleran[illegible], it is possible for the customer to select a different [illegible] for a particular need. For example, if a customer needs [illegible] of being within the tolerance window (less than one miss per 1,000 tests), he might select ± 25 KEAS (P=0.9993). See Figure 5.

However, if his requirements are for a tight tolerance, he might select ± 20 KEAS which we will hit 99 out of 100 times, or [illegible] which we will hit 80% of the time. In any event, if the customer desires, he may control his own destiny by selecting his tolerance according to his needs or the risk he is willing to take.

As a further consideration, on intermediate velocity [illegible] does not specify the velocities. It appears that the velocities are often selected rather arbitrarily. Therefore, it might be well to leave the velocity window out entirely and run no risk whatever of not ejecting.

CONCLUSIONS AND RECOMMENDATIONS The target velocity tolerance for escape system tests should not be stated in terms of per cent (%). This tolerance method does not simulate the phenomenon which occurs and has led to some serious undertesting of maximum velocities on past escape system tests. This undertesting could lead to a compromise of safety for the air crews.

The amount which an actual velocity varies from its target velocity is essentially independent of the magnitude of the target velocity. A tolerance of ±23.5 KEAS for the entire target velocity range of 0 to 600 KEAS will give an assurance against excessive over or undertesting at the maximum velocity and will require a re-test only 3 times per 1,000 tests. A drag run is always required in order to obtain this high level of accuracy.

It is the recommendation of the Test Track that a velocity tolerance of ±23.5 KEAS should generally be used on all future escape system tests. However, the customer may select another tolerance according to his needs or acceptable risks. Or, he may remove the window (and the risk) entirely on any arbitrary velocity, intermediate range tests.

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4. MENDENHALL, WILLIAM, "Introduction to Probability and Statistics", Duxbury Press, Belmont, California, 1971.

TARGET AND ACTUAL VELOCITIES

[illegible] VELOCITY (KEAS)	ACTUAL VELOCITY (KEAS) SEAT #1	SEAT #2	SEAT #3	SEAT #4
35	36.8	33.2		
80	77.7			
80	78.4	74.6		
80	81.6	78.1		
100.	96.1			
125	125.0			
133	146.1	142.9		
150	155.7	157.5		
150	158.5	158.9		
150	156.4	154.6		
175	176.4			
175	184.0	178.7		
200	191.0			
200	189.0			
240	242.0	239.1	245.7	243.2
250	247.3			
250	255.8			
250	264.4	254.4	245.3	254.3
300	289.0			
300	293.3			
300	300.0	299.7		
325	322.1	319.2	326.1	309.4
340	328.0			
400	408.0			
400	406.4	402.5		
409	417.5	411.1		
409	414.8	400.5		
450	450.5			
450	458.1			
450	461.4			
450	447.0			
450	443.2			
450	437.0			
450	417.4			
450	453.7	456.9		
450	457.3	459.4		
450	439.6	442.2	446.6	453.2
450	448.9	452.3	456.3	461.7
550	559.0	555.5	550.2	548.1
552	549.0			
576	578.7	572.4		
575	578.3	572.5		
576	569.[illegible]	575.5	580.6	587.4
600	612.[illegible]			
600	618.[illegible]			

PERCENTAGE DEVIATION FROM THE TARGET VELOCITY

TARGET VELOCITY (KEAS)	DEVIATION (%) SEAT #1	POSITIVE=ABOVE NEGATIVE=BELOW SEAT #2	SEAT #3	SEAT #4
35	5.2	-5.2		
80	-2.9			
80	-2.0	-6.8		
80	2.0	-2.4		
100	-3.9			
125	0.0			
133	9.8	7.4		
150	3.8	5.0		
150	5.7	5.9		
150	4.3	3.1	1.8	-5.9
175	0.8			
175	5.1	2.1		
200	-4.5			
200	-5.5			
240	0.8	-0.4	2.4	1.3
250	-1.1			
250	2.3			
250	5.8	1.8	-1.9	1.7
300	-3.7			
300	-2.2			
300	0.0	-0.1		
325	-0.9	-1.8	0.3	-4.8
340	-3.5			
400	2.0			
400	1.6	0.6		
409	2.1	0.5		
409	1.4	-2.1		
450	0.1			
450	1.8			
450	2.5			
450	-0.7			
450	-1.5			
450	-2.9			
450	-7.2			
450	0.8	1.5		
450	1.6	2.1		
450	-2.3	-1.7	-0.8	0.7
450	-0.2	0.5	1.4	2.6
550	1.6	1.0	0.04	-0.3
552	-0.5			
576	0.5	-0.6		
576	0.4	-0.6		
576	-1.1	-0.1	0.8	2.0
600	2.0			
600	3.2			

N = 84
MEAN = 0.38
S.D. = 3.09

DEVIATION IN KEAS FROM THE TARGET VELOCITY

TARGET VELOCITY (KEAS)	SEAT #1	SEAT #2	SEAT #3	SEAT #4
	DEVIATION (KEAS) POSITIVE = ABOVE NEGATIVE = BELOW			
35	1.8	-1.8		
80	-2.3			
80	-1.6	-5.4		
80	1.6	-1.9		
100	-3.9			
125	0.0			
133	13.1	9.9		
150	5.7	7.5		
150	8.5	8.9		
150	6.4	4.6	2.7	-8.8
175	1.4			
175	9.0	3.7		
200	-9.0			
200	-11.0			
240	2.0	-0.9	5.7	3.2
250	-2.7			
250	5.8			
250	14.4	4.4	-4.7	4.3
300	-11.0			
300	-6.7			
300	0.0	0.3		
325	-2.9	-5.8	1.1	-15.6
340	-12.0			
400	8.0			
400	6.4	2.5		
409	8.5	2.1		
409	5.8	-8.5		
450	0.5			
450	8.1			
450	11.4			
450	-3.0			
450	-6.8			
450	-13.0			
450	-32.6			
450	3.7	6.9		
450	7.3	9.4		
450	-10.4	-7.8	-3.4	3.2
450	-1.1	2.3	6.3	11.7
550	9.0	5.5	0.2	-1.9
552	-3.0			
576	2.7	-3.6		
576	2.3	-3.5		
576	-6.3	-0.5	4.6	11.4
600	12.3			
600	18.9			

N = 84
MEAN = 0.99
S.D = 7.84

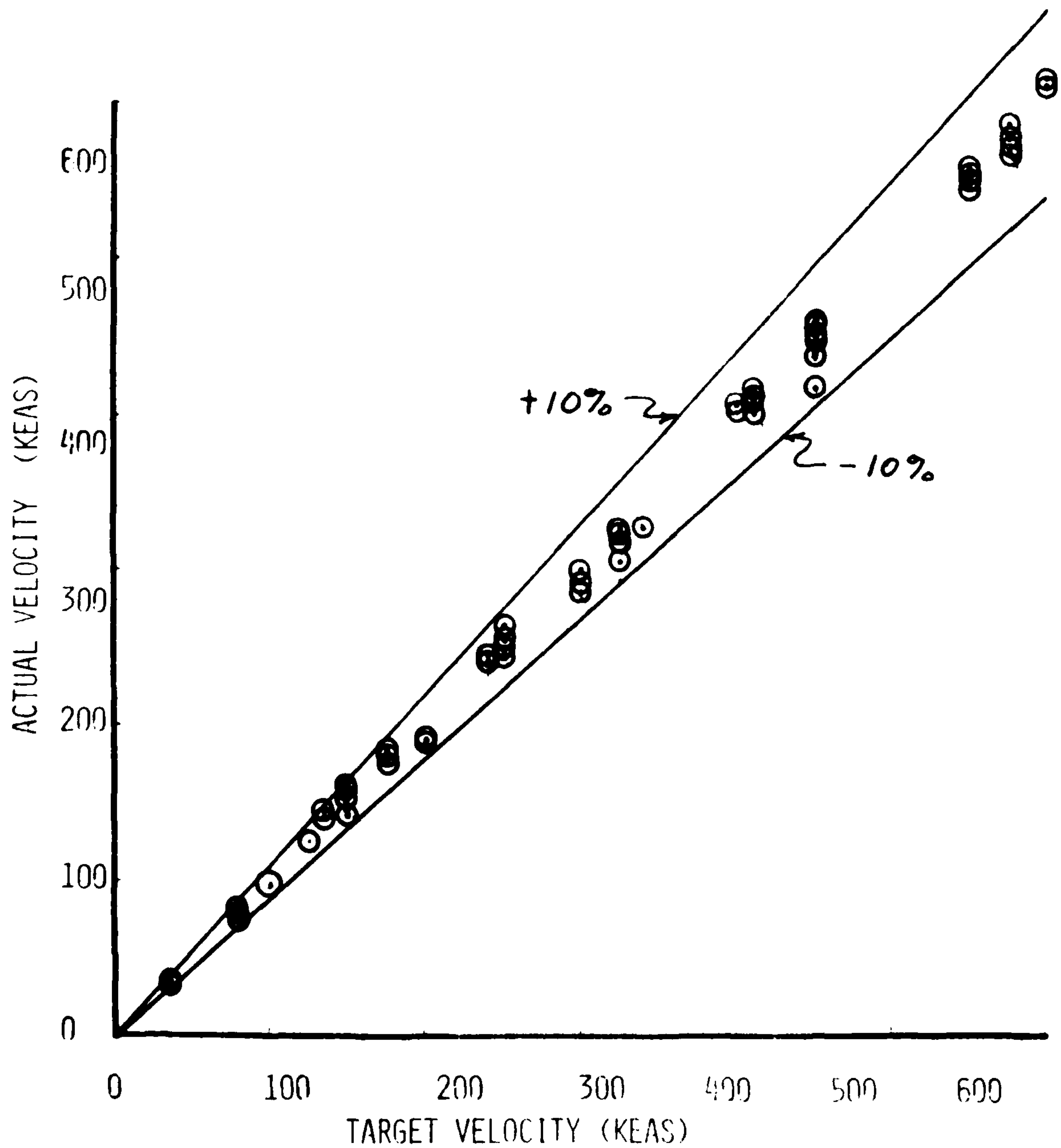


FIGURE 1. ACTUAL VELOCITY VERSUS TARGET VELOCITY

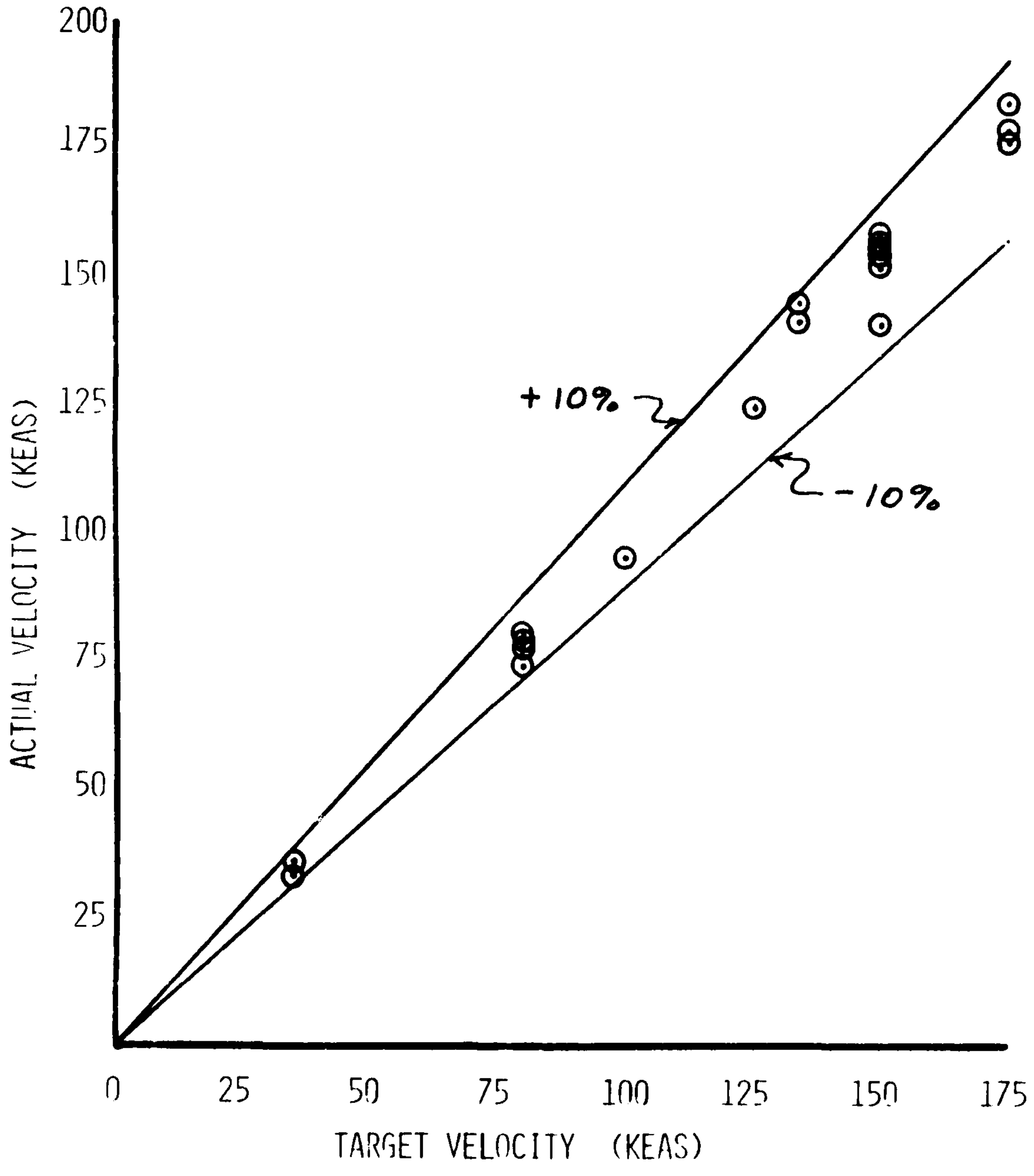


FIGURE 2. LOW VELOCITY RANGE

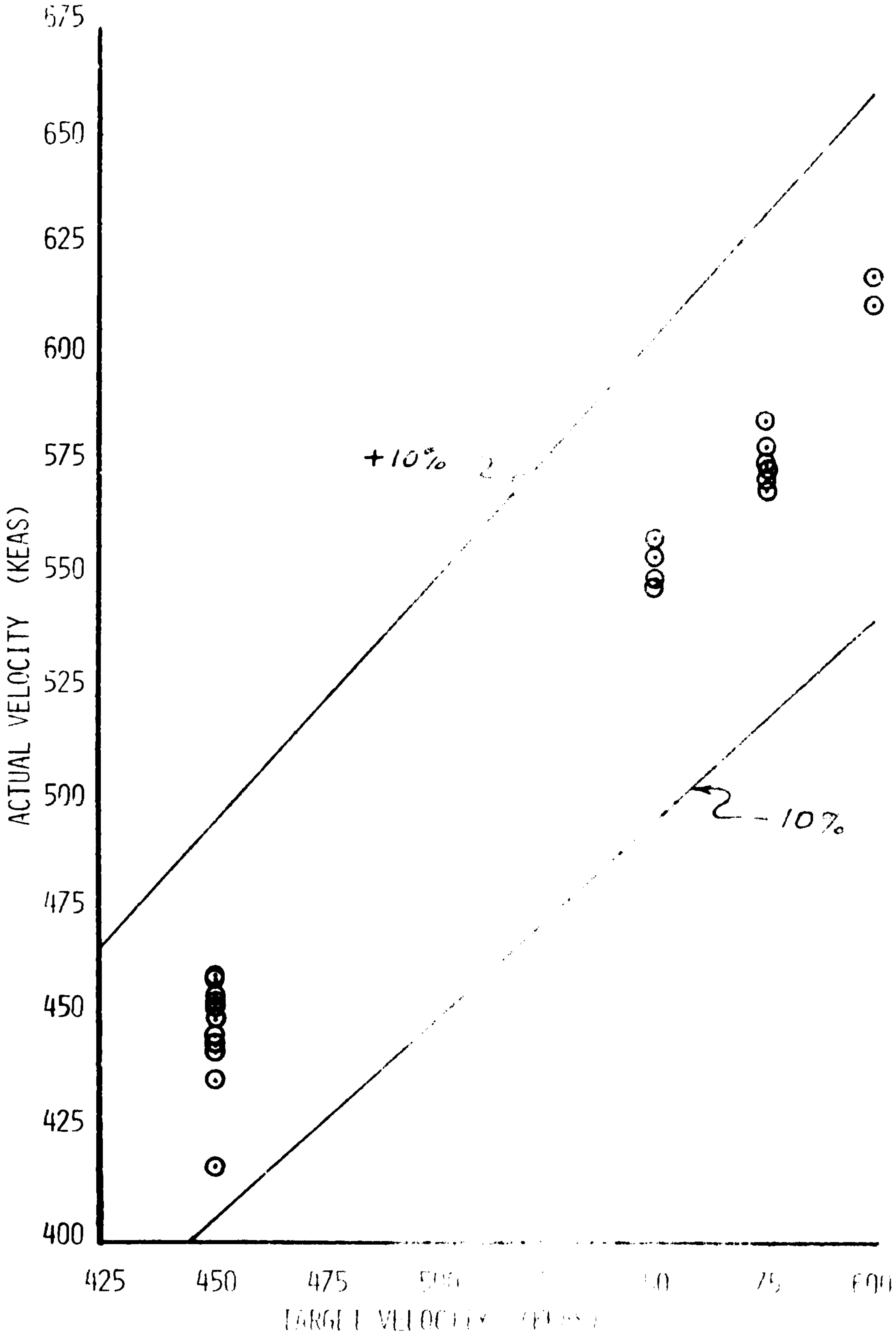

675
650
625
600
575
550
525
500
475
450
425
400
ACTUAL VELOCITY (KEAS)
+10%
-10%
425
450
475
75
TARGET VELOCITY

FIGURE 3. [illegible]

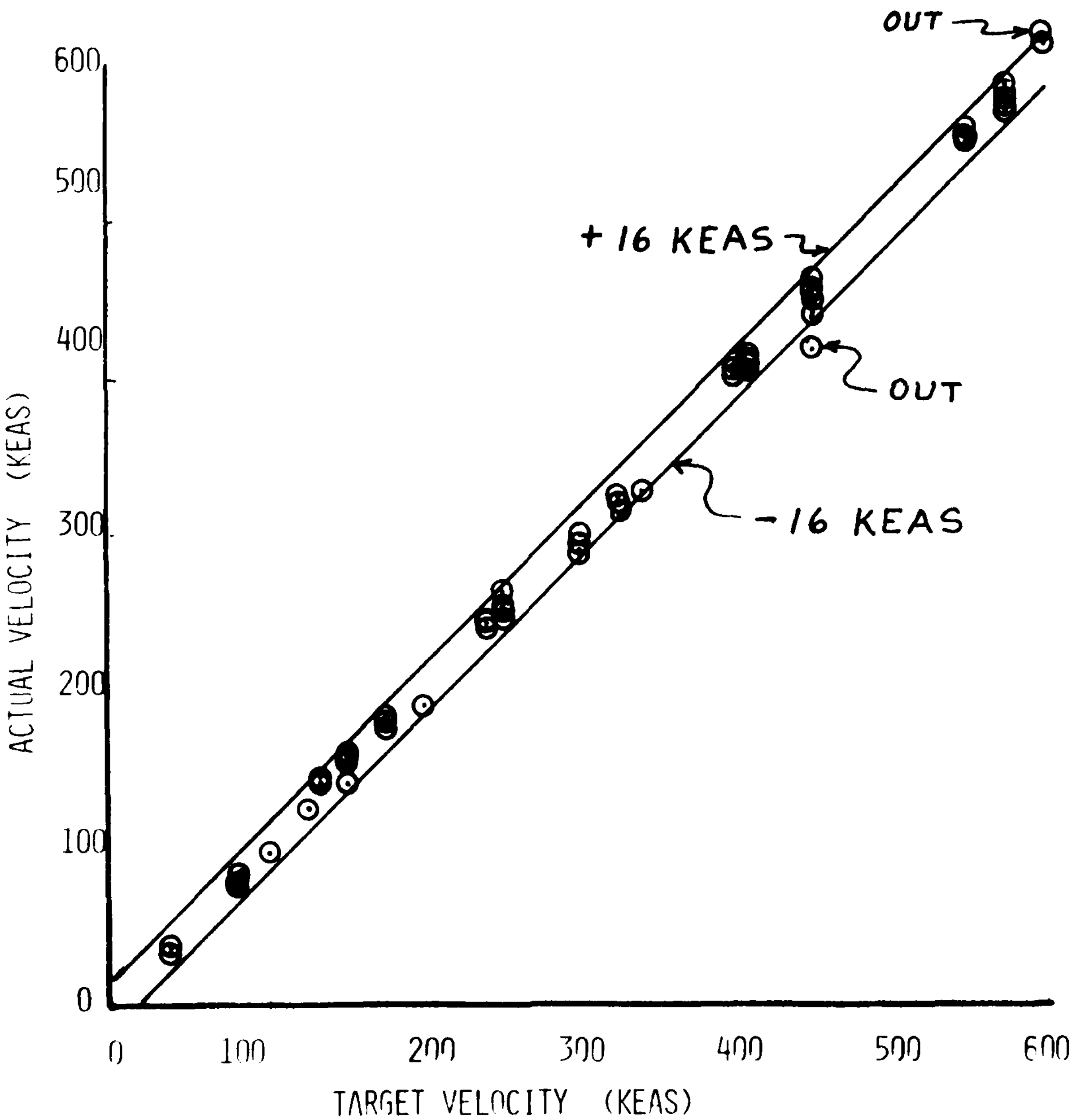


FIGURE 4. ACTUAL VELOCITY VERSUS TARGET VELOCITY

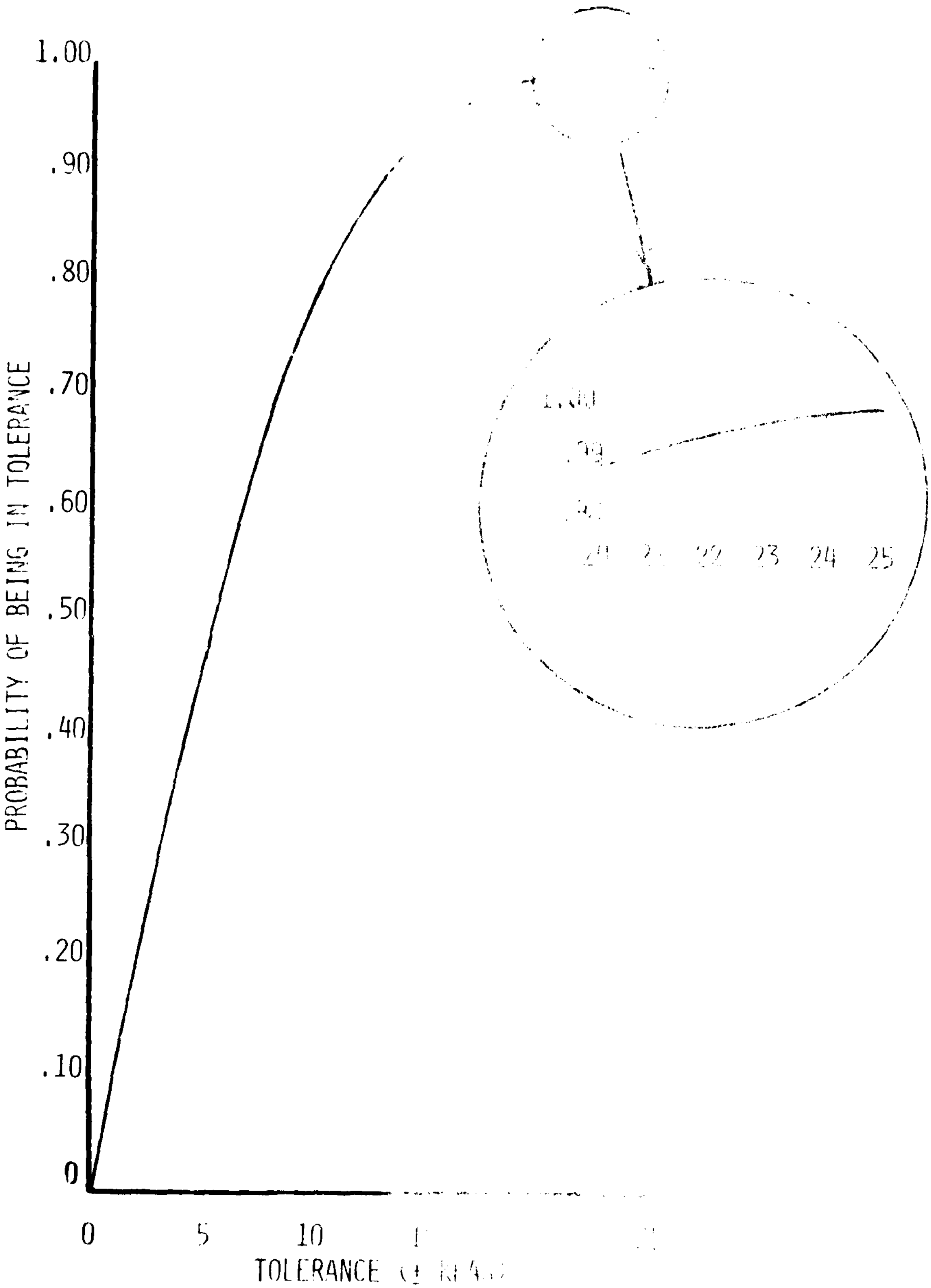
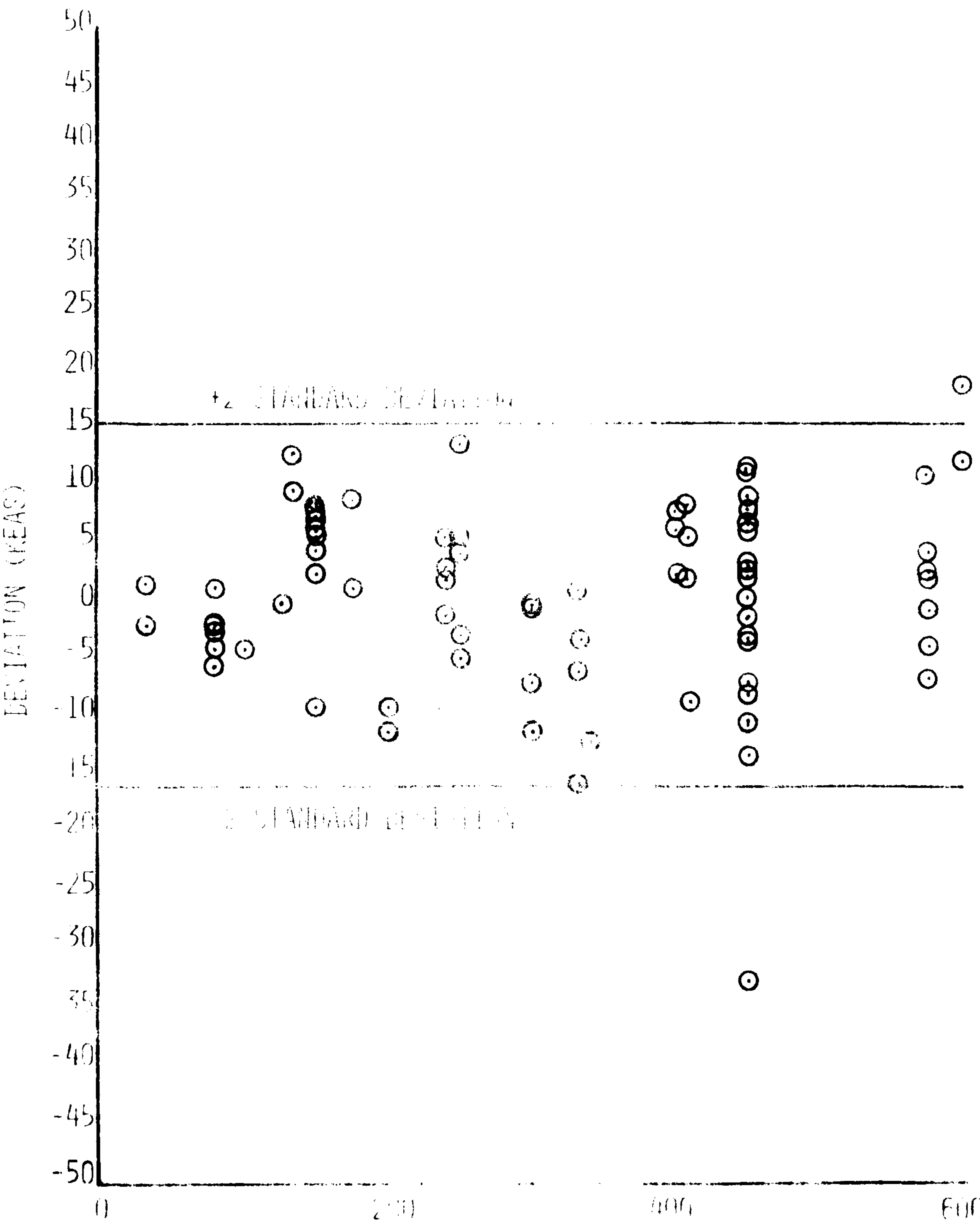


Figure 5. PROBABILITY


DEVIATION (KEAS)
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
0
200
400
600

APPENDIX A

The amount that each test deviated from its target velocity is plotted in Figure A1. From viewing these data it seems intuitively obvious that the scatter of the data, i.e., the amount the target velocity was missed, is essentially independent of the magnitude of the target velocity. This study was made to determine if there is any relationship, and if so, its strength.

If the magnitude of the data scatter is increasing or decreasing with increasing velocity it will be evident from the slope of a "Best Fit" least squares line (reference 4). However, at this point one must take care because we have both positive and negative misses. It would be possible to have the data scatter increasing or decreasing, but closely symmetrical about zero and thereby produce a near zero slope.

In order to avoid this possiblity, all data were analyzed only as to the magnitude of the miss. That is, the absolute values of the misses were used. This is reasonable from the standpoint that if one is trying to hit a velocity window, the magnitude of the miss is the concern and not whether it is plus (+) or minus (-).

This analysis showed a slope of 0.0044 KEAS per KEAS. However, its coefficient of correlation, R, was only 0.146. For a population of this size, this value of R is not significantly different from zero (using F tests) that is there is no correlation between the magnitude of the misses and the target velocity or in other words, the magnitude of the misses is independent of the target velocity.

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